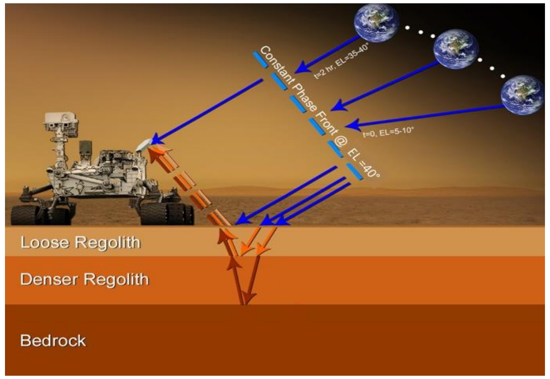

AGU FALL MEETING
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Synergistic Use of Spacecraft Telecom Links for Collection of Planetary Radar Science Data

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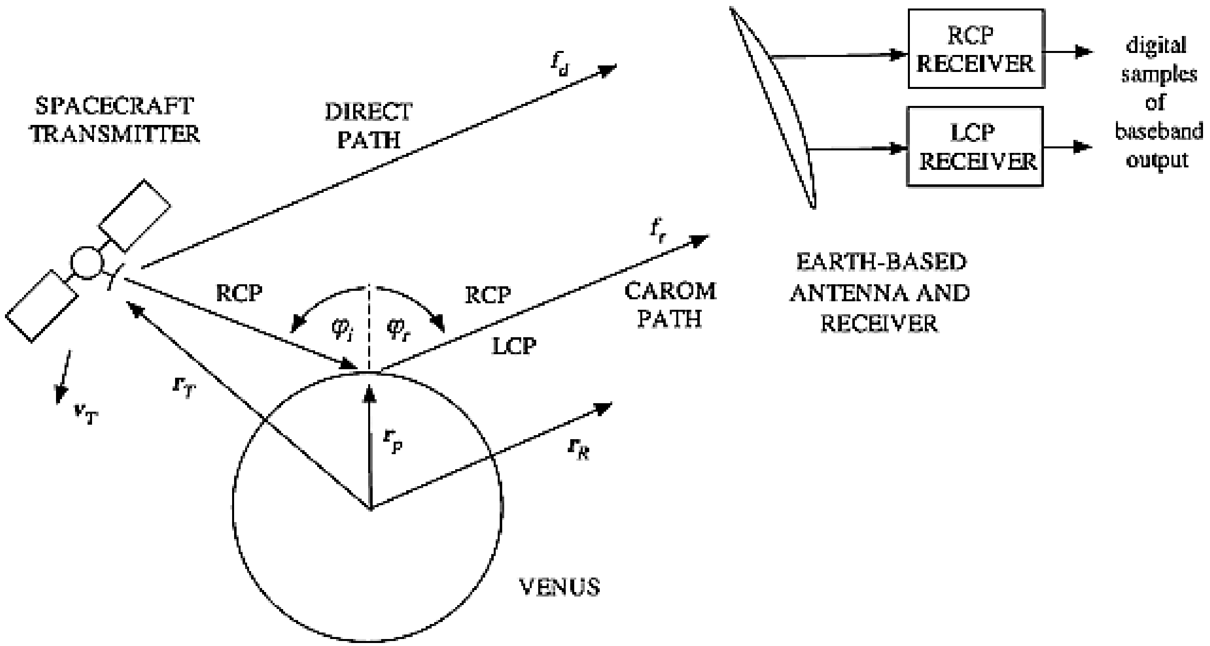
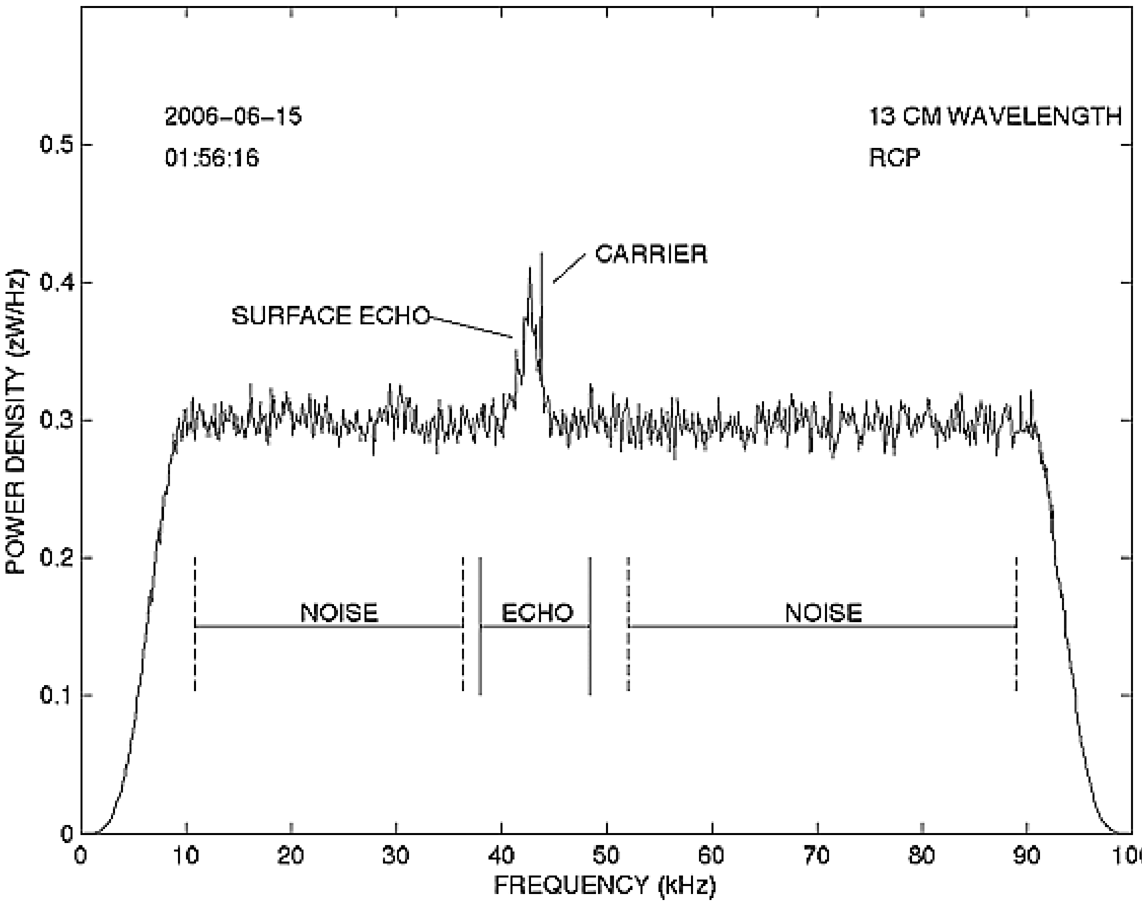
Concept of Bistatic Radar/Surface Scattering



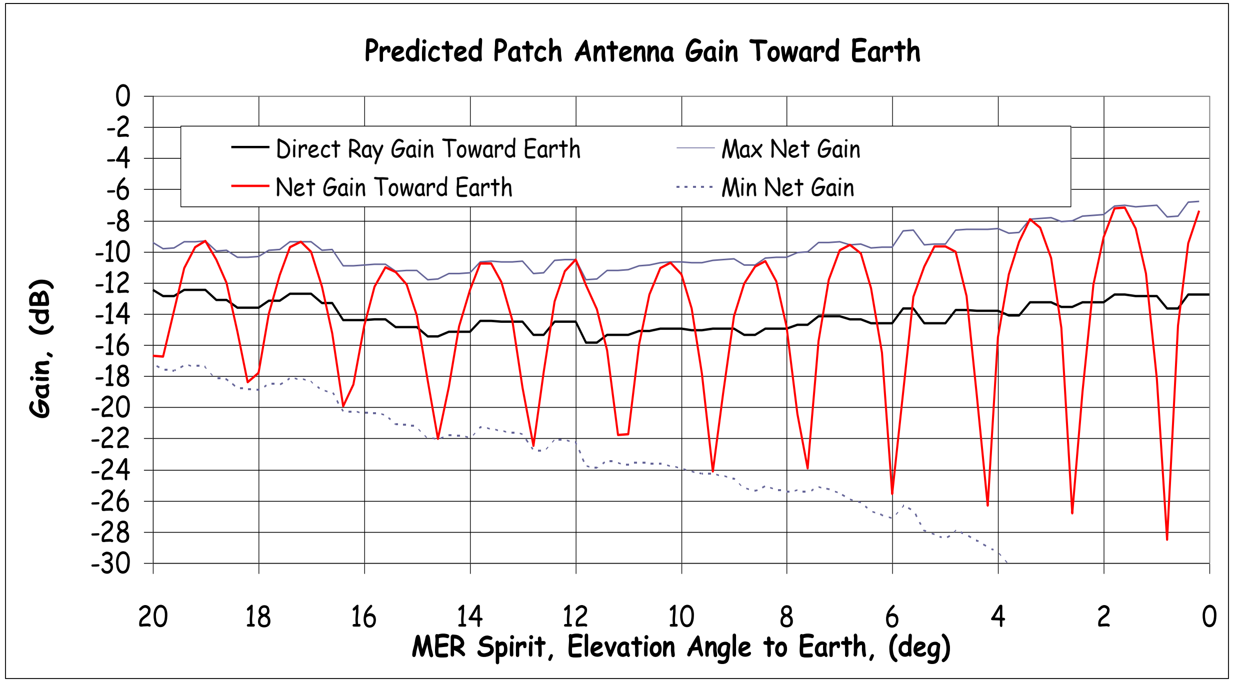


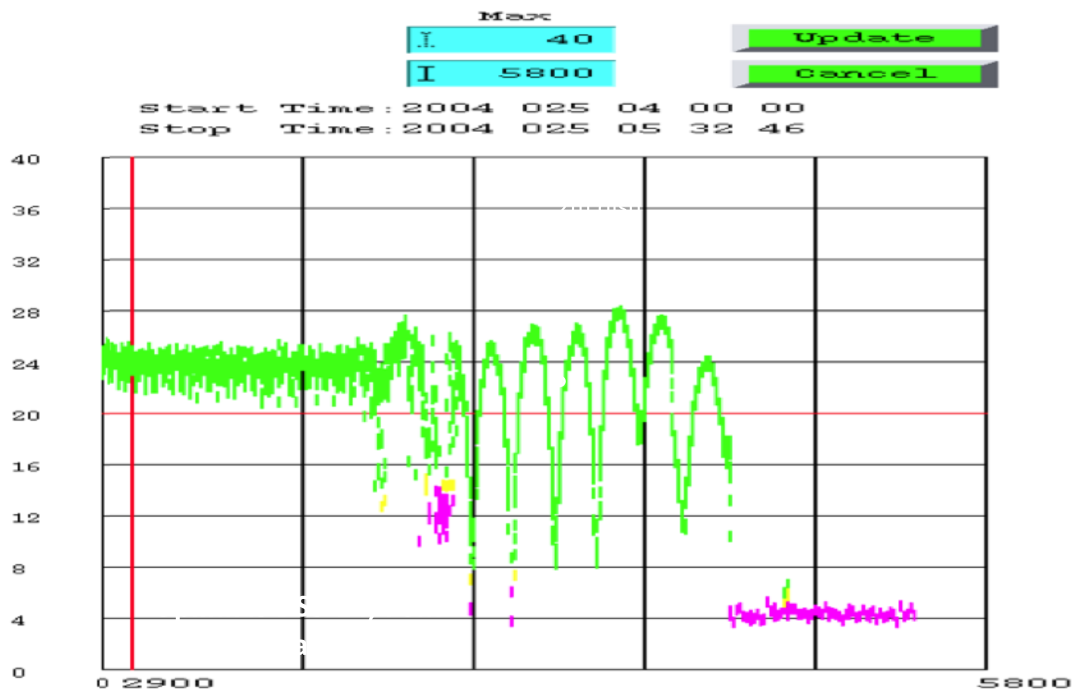
Source: R. Simpson

- With precision measurements of signal level, especially of RCP <u>and</u> LCP polarizations, information about electrical properties of material and surface roughness can be deduced
- Can be carried out from an orbiter or from a lander
- Configuration can be:
  - Downlink from spacecraft
  - Uplink from ground station
  - Spacecraft-to-spacecraft links

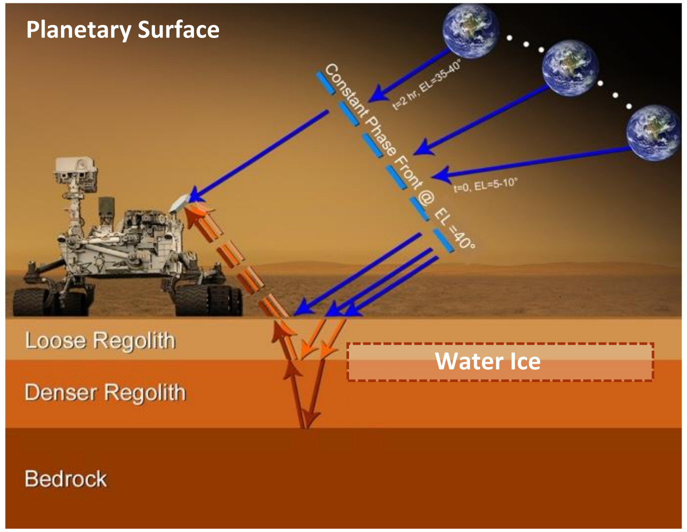
Bistatic Radar Signatures: Case of MER

- A byproduct of telecom links to/from planetary landers
- Left panel: X-band multipath signal level for Spirit Mars Exploration Rover (MER) from a model
- Right panel: Multipath signal level variation on X-band link just after landing
  - From transmitter turn on time to loss of signal, as rover view of earth was setting on local Mars horizon
- Model included direct and reflected signal path with a best guess of soil complex dielectric parameters
  - Suggested 20 dB signal variations near earth set and actual showed 20 dB signal variations

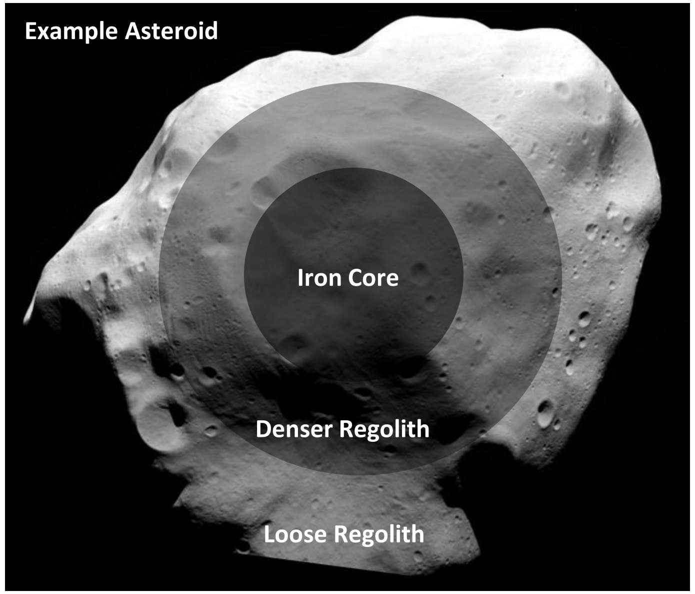




Scientific Use Cases

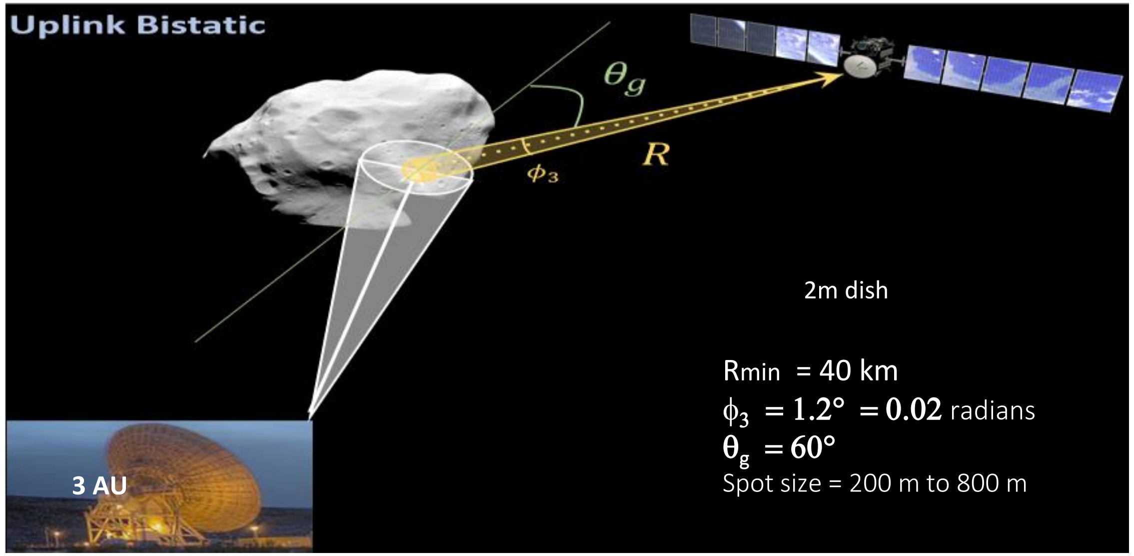


- Identify depth, density and thickness of regolith layers based on radar reflections
- Determine layer dielectric properties to help identify material types
- Multiple images form 2-d and 3-d imaging of subsurface layers
- Imaging and other science data helps interpret the radar data
- Explore soil liquid water content and flag potentially habitable zones sample sites
- Asteroids covered in regolith of dust and rubble comprised of chondrite material, Olivine/ Pyroxene with metal matrix and metal nodules and flakes
- Comet cores are mixtures of ice and chondrite; Rosetta used 90 MHz bistatic radar; lower frequency radar can penetrate lower density comets and smaller asteroids



Psyche Asteroid Example

- Metallic core of larger parent body
- Surface likely mixture of native achondrite, olivine/ pyroxene crystal, sulfur, iron/nickel and vacuum voids, possibly non-native chondrite material
- Composite mineral/metal/vacuum matrix may have dielectric permittivity from 4 to infinity
  - 4 is olivine and vacuum matrix
  - ∞ is metal and vacuum matrix
- Radar penetrates silicate layer for many meters down to metallic layer
- Monostatic Earth-based radar limited to 7.5 km/pixel
- Bi-static radar resolution ~200 m/pixel to 800m/pixel
- Bistatic radar can be used to evaluate surface roughness and porosity
  - Surface roughness partially mask dielectric properties



M.K. Shepard, et. al, "Radar observations and shape model of asteroid 16 Psyche," Icarus 281 (2017) 388–403

Mars Near Surface Use Case

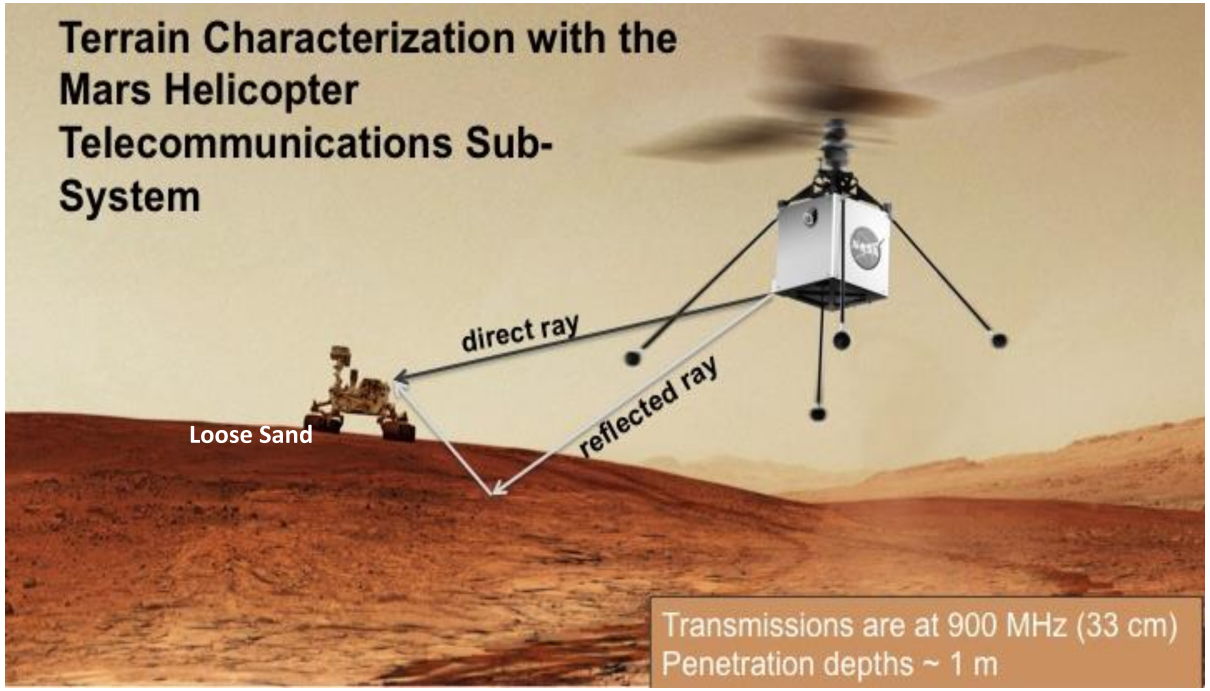
Science

- **Detection of near surface water, e.g., recurring slope linea**
- **General layering information for morphological science and to identify sites for further investigation**

Hazard Avoidance

- **Changes in Helicopter-to-Rover signal to assess sand depth along planned rover path**

Proposed Mars Helicopter utilizes a 900 MHz telecom link with the rover



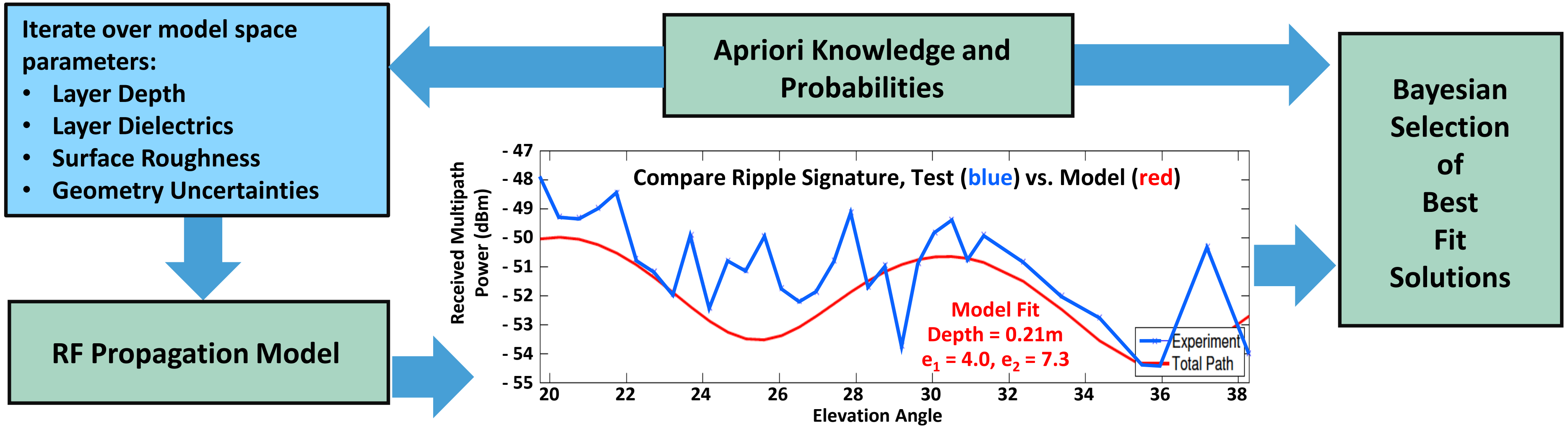
Hardware and Modeling for Helicopter Link

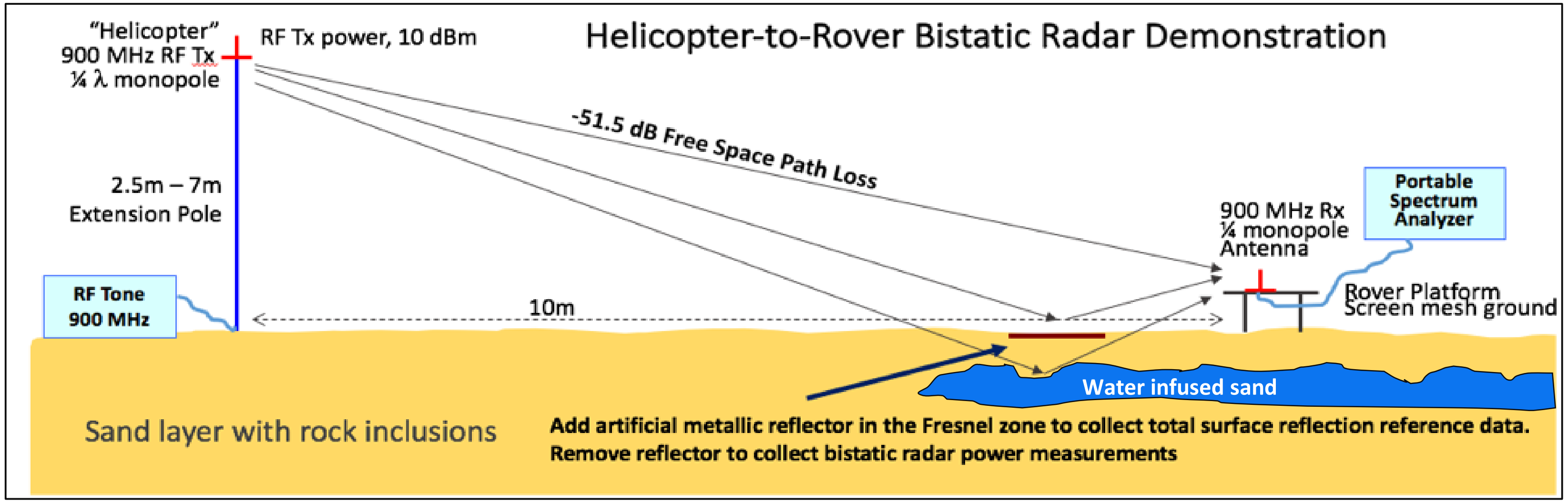
- 900 MHz (¼-wave) monopole with ground plane on top of 2-7 m extendible pole simulates helicopter link
- Second monopole on table simulates rover end of the link
- JPL Dry wash as Mars surface analog - - 9 months without rain   yet damp sand was still found at 18 cm depth
- EM response of antennas and ground effects modeled to predict antenna pattern as used in the field
- A parametric model applied to field data to perform gradient search for best fit estimates of sand layer depth for layer 1 and dielectric values of layer 1 and layer 2

- 900 MHz (33 cm) can detect thick layers of damp sand or other change in dielectric
- Cannot detect thin dielectric layers
- Cannot detect water ice with dielectric value too close to sand

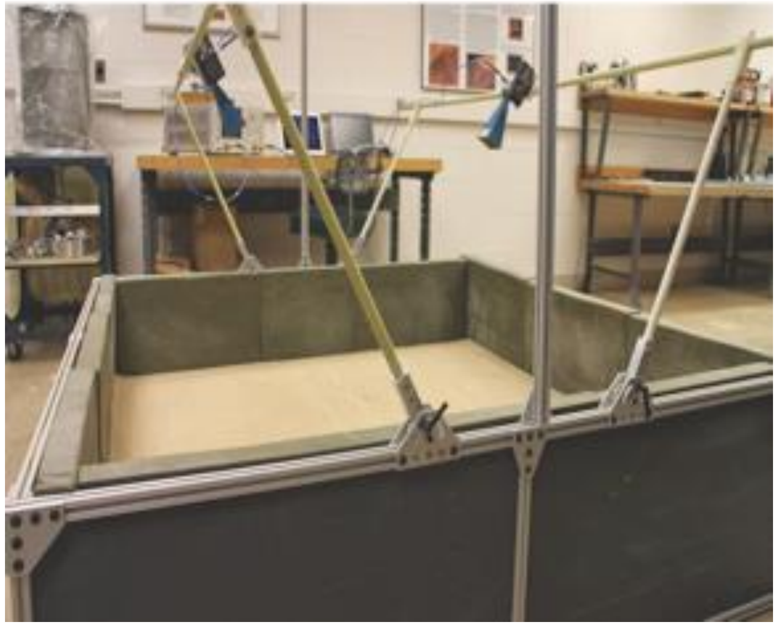
Modeling and Estimation Details

- Received power vs. elevation angle produces a multipath interference ripple signature
- Gradient search of model space produces best fit solutions to layer dielectric properties and layer depths



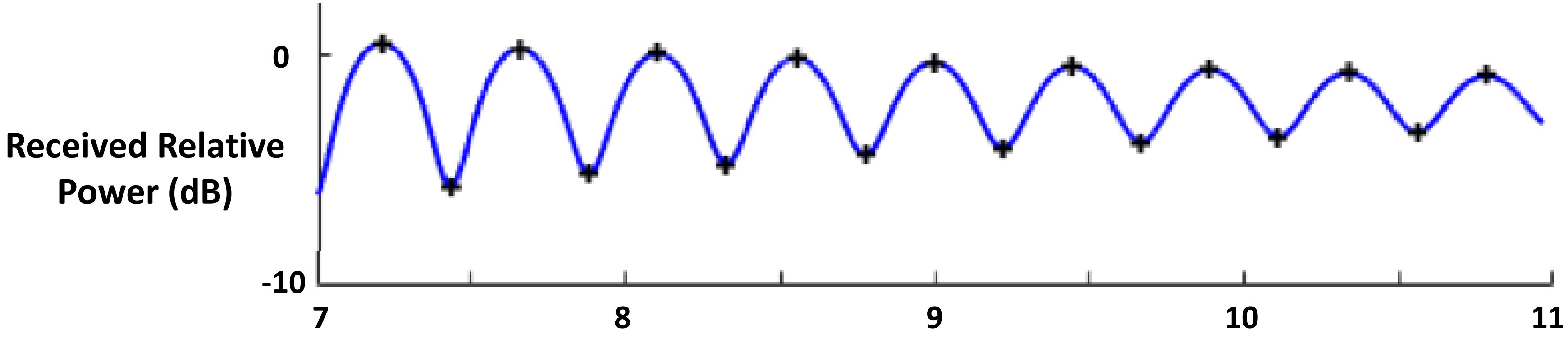


Univ. Michigan: Higher Frequency & Wider Bandwidth



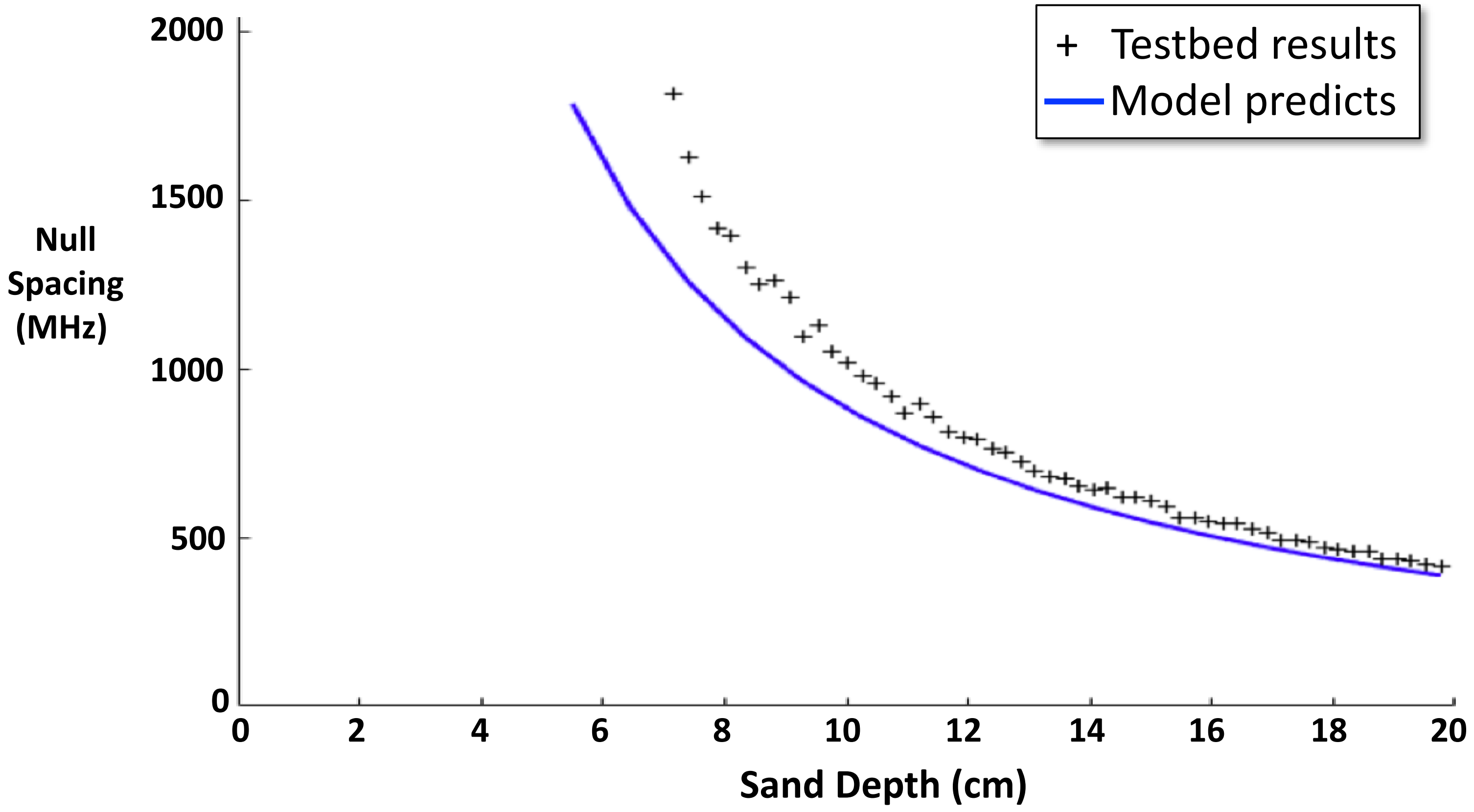
Top Layer Sand Depth = 20cm
Bottom Layer is highly reflective
Top: $\varepsilon_1 = 2.76 - j\,0.11$
Bottom: $\varepsilon_2 = 54.5 - j\,36.8$
Null Spacing = 451 MHz

- Higher frequencies enables detection of thin dielectric layers
- Wider bandwidth and frequency sweep allows detection of dielectric layers with fixed signal geometry
- Variables include: First layer sand depth, second layer dielectric type (e.g. concrete or metallic layer), surface roughness
- Sand depth resolution of 0.25cm between 6.75 cm and 20.0 cm
- Fixed Angle: 0 deg. incidence angle, (90 deg. elevation)
- Result is new metric:
  Null Spacing (GHz) vs. top layer sand depth
  Largely independent of incident angle



Robust Simple Metric for Sand Depth

- Sandbox testbed results for null spacing closely match model predicts
- Results with sand ripples and rock inclusions still showed strong correlation of model to measurement conditions



Proposed Follow-on Field Work

- Follow-on field tests at 900 MHz and X-band have been proposed with at start date in the fall of 2018
- Better Mars analog locations in California and Washington deserts have been identified
- Tests coordinated with Mars 2020 Mars Rover analog field tests, since rover will carry dedicated mono-static ground penetrating radar instrument (RIMFAX) operating from 150 MHz to 1200 MHz

Arroyo Seco wash east of JPL was site of original Caltech rocket tests and decades later the planetary radar field tests

L to R: Joshua Miller, Curtis Jin and Emmauel DeCrossas

Rudolph Schott, Apollo Milton Olin Smith, Frank Malina, Ed Forman, Jack Parsons